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Diagenesis of continental carbonate country rocks underlying surficial travertine spring deposits

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ABSTRACT

Diagenesis of Miocene-Pliocene continental rocks in extensional Teruel Basin related to deposition of a travertine at surface has been studied. Most of the diagenetic processes described here are in relation to the travertine deposition, so they are not widespread along the basin. Due to their high induration degree these rocks may be misinterpreted with travertine/tufa facies, so there is a need of clear criteria for their recognition as they can supply important hydrological and paleoenvironmental information. The diagenetic processes, that deeply modified the substrate, include dissolution, recrystallization and cementation and lead to a high induration of the Miocene-Pliocene rocks. These processes were driven by groundwater flow leading to travertine deposition at surface and appeared to be closely related to the fluvial incision of Alfambra River and to extensional fracturation during Middle Pleistocene times, probably under humid conditions. The cementation sequences and the organization of fractures and vadose micrite point to alternating vadose-phreatic conditions and syndiagenetic movements of the faults. Isotopic signal show lighter δ^{18}O than that of the unaltered Miocene-Pliocene rocks and similar δ^{13}C, suggesting lighter oxygen signal in waters during interglacial Pleistocene periods, and a common origin for carbon from marine Mesozoic rocks from the substrate of the basin. All of that suggest the strong control of tectonics, and climate at different timescales in diagenesis of the rocks serving as substrate for surficial travertine deposition.

1. Introduction

Discontinuities as joints, gravitational fractures, or even inherited volcanic structures can serve as fluid conduits allowing the flow of groundwaters to the surface (Pentecost, 2005). As a consequence of water flow, new primary calcium carbonates are then formed at surface (travertine *ss*) and in open fractures and other discontinuities (crystalline crusts). Moreover, the flow of water through the substrate may notably modify it, especially if it consists of carbonates or other permeable rocks. In these cases the travertine deposition at surface is accompanied by diagenetic modification of the underlying rocks from the substrate. Falls or risings of water table due to dry-wet climate cycles of different temporal scales (annual, decadal, centennial, etc.) can also control the hydrological system which eventually produces surficial travertine deposition, independently of the tectonic activity (Schrøder et al., 2012; De Filippis et al., 2013; Gao et al., 2013; Henchiri, 2014) and therefore the related diagenesis of the substrate.

In this study we describe the strong modifications of the substrate of the Villalba Baja travertine (Teruel Basin, Spain) by diagenesis which caused the lithification of the Neogene rocks, making it difficult in cases to distinguish between the surface travertine deposits and the diagenetically modified substrate. Although these modifications can also contain important paleoenvironmental signals, they rarely have been discussed in the literature (Goldstein, 2008; Li et al., 2014). We set out to investigate how changes in hydrology through time plus tectonic processes imprinted characteristic signatures in the rocks that are overlain by surface travertine deposition.

2. Location and geological setting

Teruel Basin is located in the East of the Iberian Peninsula, 100 km inland from Spanish Mediterranean coast. This basin is a NNE-SSW half-graben of 100 km long, 15–20 km width, filled with about 500 m of continental sedimentary rocks over a faulted and

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folded Mesozoic substrate (Alonso-Zarza and Calvo, 2000; Lafuente et al., 2008; Lafuente and Arlegui, 2009; Gutierrez et al., 2012; Ezquerro et al., 2014). Sedimentation started during Upper Eocene to Oligocene, but the most continuous sedimentation occurred through Miocene to Pliocene times. During those times clastic alluvial fan deposits formed near the basin margins and lacustrine-palustrine carbonates/evaporites occupied the center of the basin. Fluvial incision started in the beginning of the Pleistocene giving place to the formation of four fluvial terrace levels: Upper (probably Lower Pleistocene, 85–90 m above present day Alfambra River level), Middle (Middle Pleistocene, 45–65 m above actual river level), Lower (Upper Pleistocene, 15–35 m) and Recent (Holocene, 3.5–5 m) (Gutiérrez and Peña, 1976; Peña et al., 1984; Lafuente et al., 2011b; Ezquerro et al., 2014).

Teruel Basin may be subdivided into two sectors, Alfambra and Turia, which are respectively placed at North and South of Teruel city. The study area is placed at the Alfambra sector close to the small village of Villalba Baja (Fig. 1). The structure of the Miocene-Pliocene rocks from Alfambra Area consists of a wide, asymmetric syncline with gently sloped flanks, the eastern being shorter, and axis coinciding with the basin axis (Cortés Gracia and Casas Sainz, 2000). However, extensional stress dominated the tectonics of this area, and such a syncline may be due to higher subsidence in the center than in the margins of the basin (Gutierrez et al., 2012).

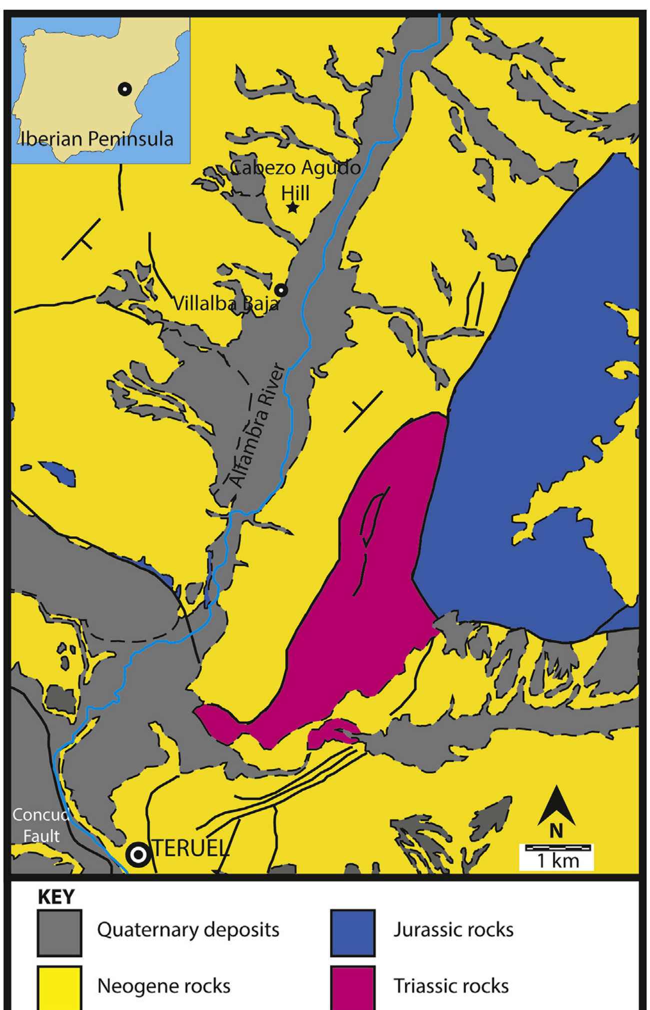

Fig. 1. Location of the study area and geological map of the Alfambra-Teruel Area (modified from MAGNA).

Tectonic evolution of the area seems to be controlled mainly by the activity of Concud fault (Simón et al., 2005; Lafuente and Arlegui, 2009; Lafuente et al., 2011a).

Travertines and tufas developed during the erosive stage since the Pleistocene (Lafuente et al., 2011b; Camuera et al., 2015). This is the case of the Villalba Baja travertine, developed on top and downslope of the Cabezo Agudo Hill which is placed at North of Villalba Baja village close to Alfambra River (Figs. 1 and 2A). Within the hill, Miocene-Pliocene lithologies have been incised and fractured so at present the hill has a crater like morphology outlined by an arcuate ridge on top and open to the Alfambra River. Both the Miocene-Pliocene rocks and the travertine are quarried for building stone.

3. Methods

70 thin sections were studied using an optical microscope. XRD analyses from 35 samples were performed using a Philips PW-1710 spectrometer with CuKα at 40 kV and 30 mA. 35 analyses of stable isotopes $\delta^{18}O$ and $\delta^{13}C$ were carried out to Scientific-technic services from Barcelona University (Spain). Description of travertine bodies was done using historic aerial photographs from the 1973–1986 Spanish Interministerial aerial images series and the rejected quarry blocks.

4. Results

4.1. Morphology of travertine bodies

The travertine occurs as different distinct bodies. The main travertine body which is actually quarried is located at the eastern end of the arc defined by the hill (Fig. 2A and B). At present neither the morphology nor the "*in situ*" facies of the travertine can be observed due to quarrying activities. So the morphology of the original build-up has been obtained through the study of the 1973–1986 Spanish Interministerial aerial images series. The main body consisted of a terraced mound-shaped carbonate body with some pool-barrier pairs. There were another four travertine bodies at the eastern side of the incised channel found at the inner part of the hill. These bodies emerged at the top of the hill and displayed fan shaped morphology (Fig. 2B). Another travertine body developed at the western side of the channel, but its morphology remains unclear from aerial photographs. A tongue of indurated rocks appeared connected to this body downslope (Fig. 2B). This tongue possesses a convex transversal profile (Fig. 3). The lowest altitude for the travertines is about 50–60 m above present day Alfambra River level. The facies of the original travertine are observed on quarry blocks left in the quarry and consist on Charophyte mounds and patches (Fig. 4A), bands made of micritic laminae which appear as gently sloping sets displaying micro-terracettes (Fig. 4B) or covering Charophyte mounds (Fig. 4C), and eventually travertine breccia (Fig. 4D).

4.2. Large scale features of the Miocene-Pliocene substrate

Miocene to Pliocene stratigraphic series developed at Cabezo Agudo Hill show a well stratified pattern, with tabular beds <0.5 m thick. The Miocene-Pliocene rocks appear tilted, dipping to Alfambra River (i.e. to the East) in the inner part of the arcuate-shaped hill, and to the west in the outer part of the hill, the inflection point being at the top of the hill.

The series is cross-cut by several fractures of ENE-WSW, NW-SE and NE-SW directions. Relationships among them are unclear. However, all these fracture directions match with those of the alpine, tertiary extensional and even late variscan tectonics (Cortés